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DATE 10 December 1963

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EVALUATION OF INCONEL 718, AGE HARDENABLE NICKEL-CHROMIUM ALLOY

REPORT A250 SERIAL NO. //

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INDEX

CODE (Ni-4)(I-e,i,k)(VI-a,e,h,l,o)

STRUCTURES LABORATORY

FINAL REPORT

EVALUATION OF INCONEL 718, AGE HARDENABLE NICKEL-CHROMIUM ALLOY

ABSTRACT

Tests were conducted to investigate fabrication characteristics of .048 inch and .250 inch thick Inconel 718. Evaluations were made in the following areas: Formability (Brake Forming, Uniform Elongation in eight inches, and Guerin and Impact Rubber Forming, and Dimple Forming); Resistance Welding, Fusion Butt Welding, and TIG Spot Welding.

Room temperature tensile tests revealed that the mechanical properties were typical for the alloy.

Total elongation and uniform elongation tests indicated good formability characteristics of the alloy in the annealed condition. A minimum bend radius of .031 inch was attained when bending specimens perpendicular to the rolling direction; a .047 inch minimum bend radius was obtained when specimens were bent parallel to the rolling direction.

Guerin Rubber Forming and Impact Rubber Forming methods were used to form .048 inch specimens on a stretch flange radius of 6.05 inches and a shrink flange radius of 9.95 inches. The specimens were formed around a .090 inch bend radius. Various flange lengths were formed to determine the amount of flange distortion that would result from each configuration. Both forming methods resulted in formed parts with approximately production tolerances.

Testing on all aged test specimens was ceased at the conclusion of the post-weld aging cycle. Pickling the aged specimens in a nitric-hydrofluoric acid solution resulted in intergranular attack which ruined the specimens for further evaluation tests. A nitric acid-nitradd pickling solution appears to produce an acceptable means of cleaning aged parts, and will be incorporated in a future evaluation of the welding characteristics of Inconel 718.

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1. INTRODUCTION

An investigation was conducted to determine the fabrication characteristics of Inconel 718, a nickel base alloy. The following tests, were authorized by TR 513-241.01:

(a) Weld patch test on .048 inch sheet in both the annealed and aged conditions. The annealed plate was aged after welding.

(b) Room temperature and 1200F mechanical properties of manual TIG welded .250 inch plate using Inconel 718, and Rene'41 filler wires. Welding was performed on annealed stock which was aged after welding.

(c) Lap shear test on resistance spot welded .048 inch Inconel 718 sheet. Welding was conducted on material in the annealed condition, and on material in the aged condition. The annealed lap shear specimens were aged after welding.

(d) Single spot tensile pull-out tests on .048 inch sheet specimens resistance welded in the annealed condition and aged after welding. Additional test weldments were fabricated for material in the aged condition.

(e) Lap shear test on TIG spot-welded .048 inch Inconel 718 welded in the annealed condition and aged after welding. Additional test weldments were fabricated for material in the aged condition.

(f) Single spot tensile pull-out tests on .048 inch sheet specimens TIG welded in the annealed condition and aged after welding. Additional test weldments were fabricated for material in the aged condition.

(g) Room temperature mechanical properties of automatic TIG welded .048 inch sheet using Rene'41 filler wire. The head travel was 4 in/min. and the chill fingers were maintained at .8 inches away from the weld bead. The test was repeated with the head travel maintained at 15 in/min with the chill fingers located .25 inches from the weld bead. Both weldments were aged after being welded.

(h) Minimum bend radius determination of .048 inch material on longitudinal and transverse specimens in both the annealed and in the aged conditions.

(i) Room temperature, longitudinal and transverse uniform elongation properties of .048 inch specimens.

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1. INTRODUCTION (cont'd.)

(j) Dimpling characteristics of aged .048 inch material.

(k) Rubber forming characteristics of annealed .048 inch specimens using the Guerin trapped rubber method in a hydraulic press, and impact forming using a drop hammer.

Inconel 718 is a relatively new nickel base super alloy. It reportedly differs from the more familiar Inconel X in that it exhibits a sluggish response to age hardening, which permits annealing and welding without the danger of cracking caused by spontaneous hardening during heating and cooling. International Nickel reports that Inconel 718 displays good ductility in the 1200-1400F temperature range with mechanical properties approximately 20 percent greater than Inconel X up to 1300F.

Testing was conducted by the Materials and Methods Group of the Structures Laboratory during the period 1 January 1962 through 7 July 1962.

2. DESCRIPTION OF TEST ARTICLE

One .048 inch thick sheet and one .250 inch thick sheet of Inconel 718 alloy were used to conduct this investigation. All test material was supplied by the Huntington Alloy Products, Division of the International Nickel Company. The vendor certifies the alloy composition of each sheet as follows:

Sheet 1 - Heat No. Y8608 - .048" x 36" x 72"

Sheet 2 - Heat No. HT4960E - .250" x 24" x 24"

Chemical Analysis

	% By Weight	
	Sheet 1	Sheet 2
C	.05	.04
Mn	.28	.23
Fe	16.58	18.00
S	.007	.007
Si	.29	.30
Cu	.05	.05
Ni	54.99	52.71
Cr	18.49	19.08
Al	.46	.35
Ti	.95	.79
Mo	2.87	3.01
Cb + Ta	4.96	5.41

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2. DESCRIPTION OF TEST ARTICLE (cont'd.)

The number of specimens required to satisfy the testing requirements were laid out on the respective sheets of stock material. The individual .048 inch thick specimen test blanks were sheared from the sheet stock using a production type Cincinnati shear, having a .0005 clearance gap between the shear blade and shear table. The .250 inch thick specimen blanks were removed from the sheet stock by sawing on a Do-All. The shearing operation presented no problem as the edges of the specimen blanks cut cleanly. Sawing the .250 inch thick material was time consuming.

Automatic TIG fusion butt welding was accomplished on .048 inch thick material using .035 inch diameter Rene'41 filler wire. Manual TIG fusion butt welding was accomplished on .250 inch thick material using both .090 inch diameter Rene'41 and .090 inch diameter Inconel 718 filler wires.

3. HEAT TREAT SCHEDULE

Testing was to be accomplished on material in both the as-received annealed condition and the as-received plus aged condition. A single aging cycle was accomplished on all test material that required aging in the following manner:

(a) Heat in an air atmosphere furnace to 1325F.

(b) Hold at 1325F for eight hours.

(c) Furnace cool to 1150F at a rate of 20F per hour.

(d) Air cool to room temperature.

Prior to heat treatment, all material was protective coated in accordance with MAC P.S. 13155. After aging, the test material was cleaned by pickling in the same manner as specified in P.S. 12050 for unaged Inconel X.

4. ROOM TEMPERATURE TENSILE TEST

4.1 Test Setup and Procedure

Three .048 inch thick tensile specimens were fabricated with the rolling direction transverse to the specimen length. The specimens were aged with the material described in section 3, page 5 , and were then tested to determine the heat treat response of the material.

The tensile specimen's dimensions conformed to Type F-2 per MAC Dwg. T-052306. The edges of each tensile specimen were polished in the gage

4.1 Test Setup and Procedure (cont'd.)

length area to remove any machining imperfections that could affect test results. Rockwell "C" scale hardness values were obtained for each specimen prior to conducting the tensile tests.

Testing was conducted in a Tatnall Test Machine. The specimen strain rate was controlled at .012 inch/inch/minute until the yield point had been reached; the strain rate was then maintained at .030 inch/inch/minute until the specimen failed. Values for ultimate tensile strength, 0.2% offset tensile yield strength, and percent elongation in two inches were recorded for each specimen.

4.2 Test Results

The room temperature mechanical properties of the heat treat response specimens are listed below:

Specimen	Hardness R_c	Fty (ksi)	Ftu (ksi)	Percent Elongation (2 in.)
1	47	173	201.5	20.5
2	47.5	172	201	21
3	47	172.5	201.5	21

Figure 1, page 22is a typical stress-strain curve plotted for the heat treat response specimens.

Figure 2, page 23, illustrates the location of failure in each of the control specimens.

4.3 Discussion of Test Results

MMS-164 specifies the following mechanical properties for aged Inconel 718, one-inch thick or less:

Ultimate Tensile Strength - 180 ksi minimum
Yield Strength at 0.2% offset - 145 ksi
Elongation in 2 inches - 12%

The mechanical properties of the control specimens exceed the requirements specified in MMS-164, and all material was deemed acceptable for further evaluation tests.

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5. UNIFORM ELONGATION TESTS

5.1 Test Setup and Procedure

Testing was conducted to determine the total elongation and the uniform elongation of annealed .048 inch thick Inconel 718. Three longitudinal and three transverse specimens were tested at 78F. The uniform elongation test specimen dimensions are listed in Figure 3, page 24.

The edges of each specimen were thoroughly polished with 2/0 grit abrasive paper in the reduced section to minimize any notch effects that surface irregularities would create during testing. Prior to testing, a grid consisting of .1 inch squares was photographically applied to each specimen. Width and thickness measurements at one inch increments were recorded for each specimen in the gage length before testing.

Testing was conducted in a Tatnall testing machine using the 75,000 pound range, and a head travel rate of 6 in/minute.

After the specimens had been tested, thickness and width measurements were recorded at the positions that were measured prior to testing. Elongation measurements were made in one-inch increments along the specimen gage length to determine the total specimen elongation. The elongation measurements, in one-inch increments, approximately equivalent to one another were averaged to determine the uniform elongation in each specimen. In addition, width and thickness measurements were recorded for the fractured surface of each specimen after testing. The failing stress of each specimen was also determined.

5.2 Test Results

Table 1, page 15, lists the test data obtained for the transverse room temperature uniform elongation specimens. Data for the longitudinal specimens are listed in Table 2, page 16.

5.3 Discussion of Test Results

Total elongation and uniform elongation test values indicate that Inconel 718 has good formability characteristics in the annealed condition. Transverse uniform elongation and total elongation values were slightly higher (approximately 3%) than comparable longitudinal properties.

6. RUBBER FORMING TEST

6.1 Test Setup and Procedure

Tests were conducted to determine the effect of Guerin trapped rubber and impact rubber forming methods on stretch and shrink flanges of .048 inch thick Inconel 718 in the annealed condition.

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6.1 Test Setup and Procedure (cont'd)

Guerin trapped rubber forming tests were conducted in a 7000 ton hydraulic press exerting a pressure of approximately 11,000 psi on the test parts. Impact forming tests utilized a Cecostamp drop hammer operating at maximum striking pressure. An 18 inch diameter trapped rubber pad was used during drop hammer forming, and a 28 in. x 45 in. trapped rubber pad was incorporated during hydroforming to develop and distribute the forming pressure evenly across the surface of the test parts. Specification of the rubber pads used throughout the test program are:

Guerin Forming - 65 - 70 durometer silicone
28 in x 45 in x 5 in thick.

Impact Forming - 65 - 70 durometer silicone
18 inch diameter x 4 inches thick.

Test parts were formed with flanges down over a Kirksite form block. No provision was incorporated in the form block to compensate for specimen spring-back. The form block had a 6.05 inch stretch flange radius and a 9.95 inch shrink flange radius. The form block incorporated bend radii of .090 inches for forming the .048 inch material. Two 3/16 inch diameter tooling pins were used for part location on the form block. The test parts were fabricated with flanges of different lengths to determine the degree of deformation peculiar to each configuration.

All edges of the test blanks were deburred and the stretch flange edge of all specimens were polished prior to forming. A grid pattern, composed of squares .1 inch on a side, was photographically applied to one side of each specimen for visually detecting material flow after forming. All bends were made parallel to the final rolling direction of the material.

6.2 Test Results

The sequence of forming operations is listed in Table 3, pages 17, 18 and 19.

The dimensions of all acceptable test parts after the rubber forming operations are listed in Table 4, page 20. Figures 4 through 7, pages 25 through 28, illustrate the configuration of the test parts after the rubber forming operations.

6.3 Discussion of Test Results

Hydroforming annealed Inconel 718 in a 7000 ton hydropress using hard lead overlays and soft lead strips, resulted in formed parts with approximate production tolerances. A minimum amount of restriking and hand working would be necessary to smooth out any deformities to produce parts to production tolerance.

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6.3 Discussion of Test Results (cont'd.)

Impact forming characteristics of annealed Inconel 718 are quite similar to those exhibited by the alloy during hydroforming operations. The hard lead overlay used during impact forming split along both flanges at the radii and did not allow for forming the test parts to the exact configuration of the form block at the radii. Additional improvement in the final configuration and tolerance of the test parts is anticipated if the hard lead overlay used during impact rubber forming were replaced by soft "commercially pure" lead overlays.

This investigation into the rubber forming characteristics of .048 inch thick annealed Inconel 718 indicates the alloy to be readily formable using standard production rubber forming methods.

7. METALLOGRAPHIC EXAMINATION

7.1 Test Setup and Procedure

A metallographic examination was conducted on fusion weldments and resistance weldments which were welded as annealed and aged afterwards, and on specimens which were welded in the aged condition. Figures 8 and 9, pages 29 and 30, illustrate intergranular attack of the base metal and weld areas when the aged fusion and resistance weldments were observed at 250X.

Testing on all aged Inconel X was ceased and an investigation was initiated to determine the cause of the observed intergranular attack. Figure 10, page 31, illustrates .048 inch thick Inconel 718 in the following conditions:

(a) as-received mill annealed
(b) aged only per section 3
(c) aged per section 3 and pickled per P.S. 12050 for unaged Inconel X.

The lower photomicrograph indicates that intergranular attack of the aged Inconel 718 material resulted from the past-aging pickling operation.

The effects of pickling aged Inconel 718 per P.S. 12050 versus time were determined using production facilities. Samples of aged Inconel 718 were pickled in fifteen minute increments until a total time of two hours had elapsed. The specimens were polished and etched and were examined at 250X for corrosion.

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7.1 Test Setup and Procedure (cont'd.)

The pickling procedure specified by P.S. 12050 was repeated on aged Inconel 718 specimens using scaled-down laboratory facilities. The nitric-hydrofluoric pickling solution was prepared fresh and the total elapsed pickling time was reduced to ninety minutes using fifteen minute increments.

The investigation was continued to determine the effects of pickling on annealed Inconel 718 using the nitric-hydrofluoric pickling solution. As-received material was re-annealed at 1750F for 15 minutes. Specimens were quenched from the annealing temperature using still air and tap water. Specimens representing both cooling media were pickled using the nitric-hydrofluoric solution for periods of 15 minutes, 30 minutes, and 45 minutes. Metallographic procedures were used to compare the extent of intergranular attack versus the applied quenching method.

The following pickling procedure is listed in Technical Bulletin T-21 published by The International Nickel Company, Incorporated for pickling high nickel alloys:

Step 1

Formula No. 7

Water	250cc
Sodium Hydroxide	66.6 gms.
Potassium Permanganate	16.75 gms.
Temperature	212F
Time	2 hours
Container	Steel Tank

Step 2

Formula No. 10

Water	250cc
Nitric Acid (42°Be')	74cc
Hydrofluoric Acid (30°Be')	12.5cc
Temperature	125F
Time	15 min. 30 min, 60 min.
Container	Polyethylene beaker

Aged specimens of Inconel 718 were pickled for 15 minutes, 30 minutes and 60 minutes, using the procedure outlined above. The pickled specimens were examined for intergranular attack using metallographic methods.

Representative specimens of aged Inconel 718 were metallographically examined for intergranular attack after undergoing the following pickling cycle:

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7.2 Test Results

Step 1

Turco Alkaline Rust Remover	2 lbs/gallon
Temperature	200F
Time	20 min.
Container	Pyrex beaker

Step 2

Turco 4338	2 lbs/gallon
Temperature	200F
Time	60 min.
Container	Pyrex beaker

Step 3

Water	53cc
Nitric Acid (42Be')	40cc
Nitradd (Turco 4104)	7cc
Temperature	78F
Time	15 min, 30 min, 60 min.
Container	Polyethylene beaker

The effects of the various pickling methods and pickling times were compared, using photomicrographs taken at 250X to determine if an effective method for preventing intergranular attack in Inconel 718 had been found. All metallographic specimens were etched electrolytically, using a hydrochloric acid - 3% hydrogen peroxide electrolyte.

The photomicrographs in Figures 11 and 12, on pages 32 and 33 illustrate the effects of pickling aged Inconel 718 using production facilities per P.S. 12050 (HNO_3-HF). Figures 13 and 14, pages 34 and 35, illustrate the effects of pickling aged Inconel 718 per P.S. 12050 (HNO_3-HF) using laboratory facilities. The photomicrographs in Figure 15, page 34, indicates the intergranular attack when Inconel 718 was pickled per P.S. 12050 (HNO_3-HF) after being re-annealed and air quenched. Figure 16, page 37, indicates intergranular attack when Inconel 718 was pickled per P.S. 12050 (HNO_3-HF) after being re-annealed and water quenched. Figure 17, page 38 illustrates the effect of pickling aged Inconel 718 using the process outlined by The International Nickel Company. The results of pickling aged Inconel 718 using the three step procedure outlined above are presented in Figure 18, page 39.

7.3 Discussion of Test Results

The nitric acid-nitradd pickling solution appears to acceptably pickle aged Inconel 718 with little evidence of intergranular attack after 30 minutes. All of the other pickling solutions which were investigated resulted in noticeable intergranular attack in aged Inconel 718 after 15 minutes pickling duration

7.3 Discussion of Test Results (cont'd.)

Intergranular attack was prevalent in the annealed Inconel 718 specimens which were pickled per P.S. 12050 using a nitric-hydrofluoric acid solution.

It is suggested that additional pickling evaluation tests be conducted using the nitric acid-nitradd pickling solution on aged Inconel 718 to confirm the results of this investigation due to the limited number of specimens which were examined. In addition, tests using the nitric acid-nitradd pickling solution on annealed Inconel 718 should be investigated, since no tests were conducted for this combination during this investigation.

The intergranular attack of the aged tested specimens which resulted from pickling per P.S. 12050 necessitates rerunning the following portions of this TR:

(a) weld patch test
(b) manual TIG fusion welding of .250 inch thick plate.
(c) resistance spot welded lap shear test
(d) resistance spot welded cross tension test
(e) TIG spot welded lap shear test
(f) TIG spot welded cross tension test.
(g) bend radius test on aged material.
(h) dimple forming test.
(i) mechanical properties of automatic TIG welded .048 inch sheet varying the welding head travel and chill spacing.

Test results of the aged test specimens will be reported for an addendum test request after an acceptable post-aging pickling procedure is established.

8. MINIMUM BEND RADIUS

8.1 Test Setup and Procedure

Tests were conducted to determine the minimum bend radius for .048 inch thick Inconel 718 in the annealed condition.

Twelve test specimens measuring 1.0 in x 2.5 in. were sheared with the final rolling direction parallel to the 1.0 inch side and twelve were fabricated with the grain direction perpendicular to the 1.0 inch side. The effects of shearing were removed from the 2.5 inch side by sanding with 80 grit abrasive paper on a wet belt sander.

The vertical brake used for this test has a 3 inch stroke and operates at 30 strokes per minute. Figure 19, page 40, illustrates the bend radius test tool that was used to form the bends. The specimens were bent with the bend axis parallel to the 2.5 inch side. The die throat opening of

FINAL REPORT

8.1 Test Setup and Procedure (cont'd.)

the test tool was adjusted to be equal to twice the radius of the mandrel plus two and one-half times the test specimen thickness. The radius of the male die was progressively increased until three specimens could be bent through 130° without evidence of failure in the bend area. After each specimen was bent, it was measured to determine the amount of spring-back in degrees that had occurred. The minimum bend radius was determined to be the measured inside radius, after spring-back, of those specimens which were acceptably bent around the smallest radius bend mandrel.

During the bending operation, individual specimens were examined for defects with a 10x magnifier. Penetrant inspection methods were used to verify the visual inspection of the bend specimens.

8.2 Test Results

Table 5, page 21, lists the bend radius test results for the annealed Inconel 718 material.

8.3 Discussion of Test Results

Bending specimens around a.031 inch radius mandrel with the final rolling direction perpendicular to the bend axis resulted in a measured minimum inside bend radius of 1/32 inch. A 3/64 inch measured minimum inside bend radius resulted from bending the specimens around a .047 inch radius mandrel with the final direction of rolling parallel to the bend axis.

9. CONCLUSIONS

Room temperature tensile tests indicate that the Inconel 718 used in this investigation possessed mechanical properties that are typical for the alloy.

Uniform elongation and minimum bend radius test results indicate that annealed Inconel 718 should have good formability characteristics. The case with which annealed Inconel 718 was formed using both the Guerin trapped rubber, and the impact rubber forming methods further attests to the good formability characteristics of the alloy.

Intergranular attack was present in both annealed and aged Inconel 718 material that was pickled per P.S. 12050 using a nitric-hydrofluoric acid pickling solution. A nitric acid-nitradd pickling solution appears to acceptably pickle both annealed and aged Inconel 718 with little evidence of intergranular attack after 30 minutes. Additional testing on welded Inconel 718 will be conducted in a later phase of testing using the nitric acid-nitradd solution for pickling purposes. Dimple forming characteristics of of the alloy will also be investigated.

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LIST OF EQUIPMENT AND INSTRUMENTS

Equipment and instruments used in this test are listed below. Applicable calibration records are available for inspection.

Item	Manufacturer and Model Number	Serial or Laboratory Number
Universal Tensile Test Machine	Tatnall 150,000 lb S/N U-112-4R	MAC 35627
Niagra Press Brake	Niagra Machine and Tool Co. Model 150-6-8	USN 890097
Metallograph	Bausch and Lomb Optical Serial No. JE04	USN912444
Drop Hammer	Chambersburg Ceco Stamp	USN 701591
Hydropress 7000 ton capacity	Hydraulic Press Mfg. Co. Mt. Gilead, Ohio	USN 804168
Bend Radius Test Tool	Mfg. at MAC	T-041122
Hardness Tester	Clark Instrument Inc. Model C16A	USN 92833

REFERENCES

1.	MAC P.S. 12050	Pickling
2.	MAC Laboratory Engr. Dwg. T-052306	Specimens - Mechanical Properties
3.	MMS-164	Nickel Alloy, Sheet Strip, and Plate (Inconel 718)
4.	Technical Bulletin T-21	Pickling High Nickel Alloys Huntington Alloy Products Div. International Nickel Company, Inc.
5.	MAC P.S. 13155	Protective Coating for Steel and Titanium during heat treatment.
6.	Certificate of Chemical Analysis (Inco Order 5796861)	Huntington Alloy Products Div. The International Nickel Co. Inc.

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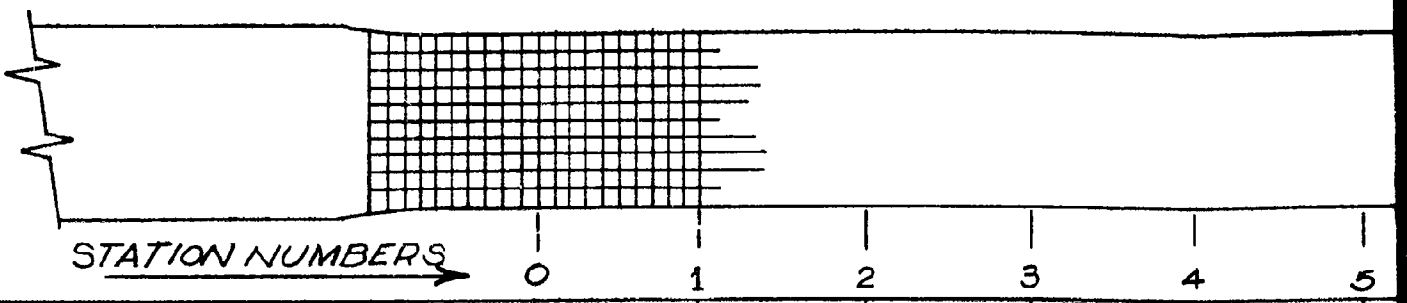
TABLE 1

UNIFORM ELONGATION TEST RA
.048 INCH GAUGE, ANN
TRANSVERSE SPECIME



ELONGATION MEASUREMENTS (IN.)		1.45	1.47	1.50	1.52	1.61	
PERCENT ELONGATION	UNIFORM	← 48.5 → ▲ W= .772 T= .026					
	TOTAL	← 48.4					
WIDTH (IN.)	BEFORE	1.007	1.007	1.008	1.0085	1.0085	1.006
	AFTER	.852	.839	.832	.828	.801	.833
THICKNESS (IN.)	BEFORE	.0489	.0488	.0488	.0486	.0487	.048
	AFTER	.0407	.0401	.0399	.0394	.0383	.039

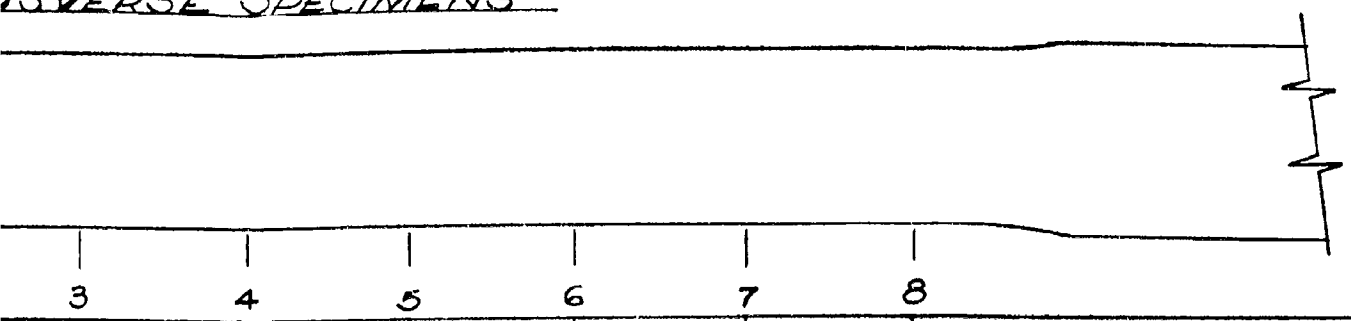
ELONGATION MEASUREMENTS (IN.)		1.39	1.40	1.43	1.47	1.61	
PERCENT ELONGATION	UNIFORM	← 42.3 → ▲ W= T=					
	TOTAL	← 46.6					
WIDTH (IN.)	BEFORE	1.0085	1.0085	1.008	1.0075	1.0065	1.006
	AFTER	.866	.861	.854	.843	.828	.790
THICKNESS (IN.)	BEFORE	.0488	.0490	.0488	.0489	.0490	.048
	AFTER	.0415	.0413	.0410	.0407	.0400	.038

ELONGATION MEASUREMENTS (IN.)		1.44	1.46	1.61	1.52	1.47	
PERCENT ELONGATION	UNIFORM	W= .782 T= .0291 ▲					
	TOTAL	← 46.5					
WIDTH (IN.)	BEFORE	1.009	1.009	1.009	1.009	1.009	1.009
	AFTER	.855	.843	.834	.806	.834	.846
THICKNESS (IN.)	BEFORE	.0493	.0496	.0493	.0492	.0494	.049
	AFTER	.0414	.0411	.0402	.0389	.0404	.040

▲ LOCATION OF FAILURE AND APPROXIMATE WIDTH

TABLE 1

GATION TEST RESULTS OF INCONEL 718
4 GAUGE, ANNEALED CONDITION
LSVERSE SPECIMENS



0	1.52	1.61	1.46	1.43	1.43	SPECIMEN NO. UE.4
		W= .772 T= .0260				
		48.4				MECHANICAL PROPERTIES (PSI) Ftu 123,900
1.0085	1.0085	1.008	1.007	1.0065	1.0065	
.828	.801	.833	.844	.848	.848	
.0486	.0487	.0484	.0484	.0482	.0480	
.0394	.0383	.0396	.0402	.0403	.0400	

73	1.47	1.61	1.53	1.46	1.44	SPECIMEN NO. UE.5
		W= .789 T= .0270				
		46.6				MECHANICAL PROPERTIES (PSI) Ftu 125,200
1.0075	1.0065	1.006	1.006	1.006	1.0065	
.843	.828	.790	.833	.843	.855	
.0489	.0490	.0489	.0490	.0491	.0491	
.0407	.0400	.0382	.0405	.0408	.0414	

1	1.52	1.47	1.44	1.40	1.38	SPECIMEN NO. UE. 6
2 91		44.2				
		46.5				MECHANICAL PROPERTIES (PSI) Ftu 124,700
1.009	1.009	1.009	1.0085	1.008	1.008	
.806	.834	.846	.855	.862	.872	
.0492	.0494	.0493	.0493	.0491	.0490	
.0389	.0404	.0408	.0412	.0415	.0418	

PPROXIMATE WIDTH AND THICKNESS MEASUREMENTS

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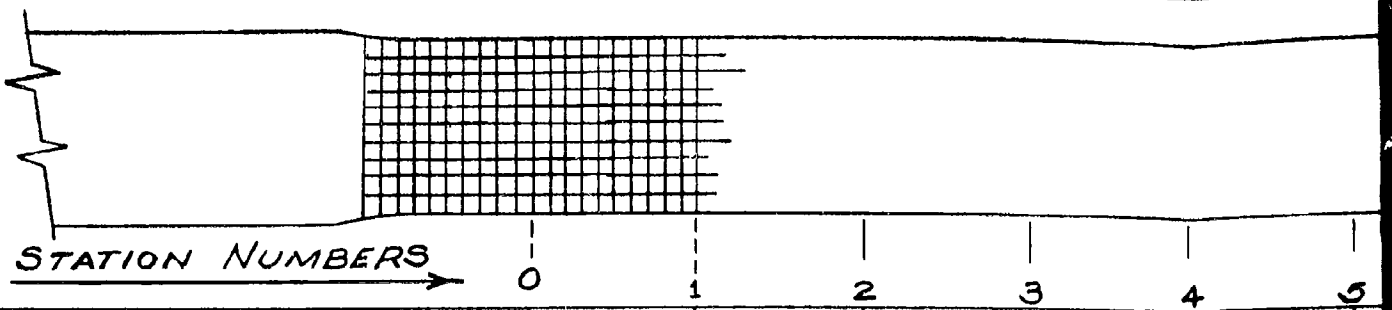
TABLE 2

UNIFORM ELONGATION TEST RESULTS OF
.048 INCH GAUGE, ANNEALED COND
LONGITUDINAL SPECIME



ELONGATION MEASUREMENTS (IN.)		1.38	1.35	1.44	1.60	1.45	
PERCENT ELONGATION	UNIFORM				W= .788 ▲ T= .0277		
	TOTAL	←				42.5	
WIDTH (IN.)	BEFORE	1.008	1.008	1.0085	1.0085	1.0085	1.008
	AFTER	.843	.876	.861	.826	.827	.850
THICKNESS (IN.)	BEFORE	.0488	.0489	.0490	.0490	.0491	.049
	AFTER	.0408	.0426	.0419	.0402	.0404	.041

ELONGATION MEASUREMENTS (IN.)		1.40	1.41	1.42	1.46	1.48	
PERCENT ELONGATION	UNIFORM	←			43.9		
	TOTAL	←			45.5		
WIDTH (IN.)	BEFORE	1.008	1.008	1.008	1.009	1.008	1.008
	AFTER	.856	.853	.850	.843	.832	.832
THICKNESS (IN.)	BEFORE	.0491	.0492	.0491	.0491	.0489	.048
	AFTER	.0420	.0418	.0415	.0411	.0406	.040

ELONGATION MEASUREMENTS (IN.)		1.61	1.48	1.45	1.44	1.42	
PERCENT ELONGATION	UNIFORM	▲ W= .775 T= .0297				42.4	
	TOTAL	←			44.8		
WIDTH (IN.)	BEFORE	1.001	1.000	1.000	1.000	1.000	1.000
	AFTER	.821	.816	.827	.831	.837	.843
THICKNESS (IN.)	BEFORE	.0489	.0490	.0490	.0491	.0489	.049
	AFTER	.0400	.0401	.0407	.0409	.0411	.041

▲ LOCATION OF FAILURE AND APPROXIMATE WIDTH AND

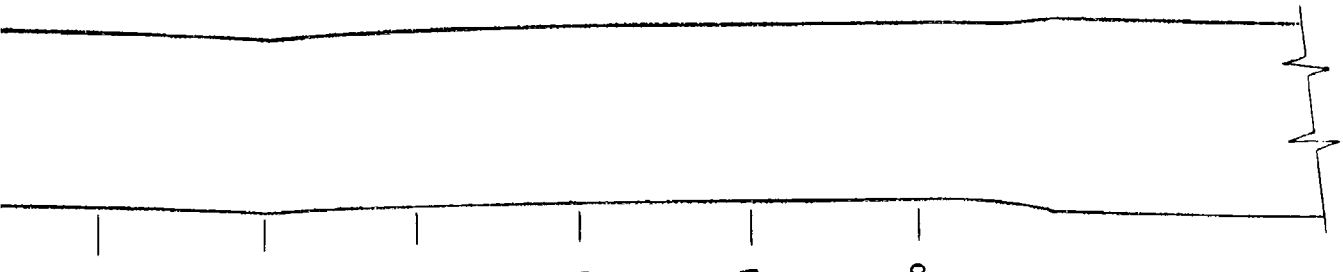
MAC 318U (REV 25 AUG 61)

[redacted]

TABLE 2

T RESULTS OF INCONEL 718
NNEALED CONDITION
TUDINAL SPECIMENS

FINAL REPORT



44	1.60	1.45	1.38	1.38	1.42	SPECIMEN NO. U.E.1
	W= .788 ▲ T= .0277	40.8 →				
	42.5 →					MECHANICAL PROPERTIES (PSI)
	1.0085	1.0085	1.008	1.008	1.0075	1.008
	.826	.827	.850	.866	.854	.850
	.0490	.0491	.0491	.0492	.0490	.0490
	.0402	.0404	.0414	.0424	.0417	.0414

Ftu 126,700

42	1.46	1.48	1.46	1.44	1.57	SPECIMEN NO. U.E.2
					W= .779 ▲ T= .0306	
	43.9 →					
	45.5 →					MECHANICAL PROPERTIES (PSI)
	1.009	1.008	1.008	1.008	1.0075	1.0075
	.843	.832	.832	.843	.841	.779
	.0491	.0489	.0488	.0490	.0489	.0488
	.0411	.0406	.0406	.0409	.0409	.0378

Ftu 126,800

45	1.44	1.42	1.41	1.39	1.38	SPECIMEN NO. U.E.3
		42.4 →				
	44.8 →					MECHANICAL PROPERTIES (PSI)
	1.000	1.000	1.000	1.000	1.000	1.000
	.831	.837	.843	.846	.849	.852
	.0491	.0489	.0491	.0491	.0492	.0490
	.0409	.0411	.0417	.0416	.0419	.0421

Ftu 125,700

KIMATE WIDTH AND THICKNESS MEASUREMENTS

FINAL REPORT

TABLE 3

FORMING SEQUENCE

MATERIAL: INCONEL 718

SHEET THICKNESS: .048 INCH

Spec. No.	Operation	Remarks
1	7000 Ton Hydropress	1.40 stretch flange .86 shrink flange (1) Three wrinkles (approx. 2 inch equidistant) in shrink flange, diagonal buckel in stretch flange ends.
2	7000 ton Hydropress *1/2 inch hard lead overlay with 3 soft lead straps	1.40 stretch flange .86 shrink flange (1) One slight wrinkle in shrink flange, slight web warpage.
3	7000 ton Hydropress *1/4 inch hard lead overlay with 3 soft lead straps	1.40 stretch flange .86 shrink flange (1) Very slight wrinkles in web at shrink flange ends, slight web warpage.
4	7000 ton Hydropress *1/2 inch hard lead overlay with 5 soft lead straps	1.40 stretch flange .86 shrink flange (1) No wrinkles in either flange, slight web warpage
A1	7000 ton Hydropress *1/2 inch hard lead overlay with 3 soft lead strips	1.60 stretch flange 1.06 shrink flange (1) Part shifted toward the shrink flange causing distortion around the tooling holes (2) Slight wrinkles 1 inch long in web at both ends of shrink flange, slight wrinkling at center of shrink flange, some web warpage.
A2	7000 ton Hydropress same as A1 except lead strips placed at wrinkled areas in A1	1.60 stretch flange 1.06 shrink flange (1) Wrinkles are smaller (2) Lead strip curled under stretch flange at middle and bent it slightly. (3) Slight wrinkles in web 1/2 inch long at ends of shrink flange.

FINAL REPORT

TABLE 3 (cont'd.)

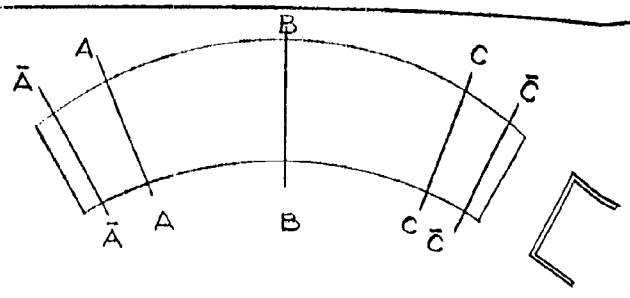
Spec. No.	Operation	Remarks
A3	7000 ton Hydropress Same as A1 except lead strips cut shorter	1.60 stretch flange 1.06 shrink flange (1) Stretch flange not completely formed and bent out slightly in center of bottom edge. (2) Small wrinkles remain at ends of shrink flange. (3) Slight web warpage
B1	Impact rubber formed *1/2 inch hard lead overlay	1.40 stretch flange .860 shrink flange (1) Slight web warpage (2) Slight wrinkling of shrink flange, slight wrinkling at ends of stretch flange.
B2	Impact rubber formed same as B1 Restrike 2 times without overlay to eliminate wrinkles	1.40 stretch flange .860 shrink flange (1) Slight web warpage (2) Small wrinkles still present in shrink flange.
A4	Impact rubber formed *1/2 inch hard lead overlay (1) Wrinkles worked lightly with mallet (2) Restrike with rubber pad (3) Restrike no rubber pad	1.60 stretch flange 1.06 shrink flange (1) Slight web warpage (2) Wrinkles not completely removed from shrink flange. (3) Small wrinkle present at end of stretch flange.
A5	Impact rubber formed (1) Soft lead strip overlay at shrink flange (2) Restrike without overlay	1.60 stretch flange 1.06 shrink flange (1) Slight web warpage (2) Small wrinkles present in shrink flange. (3) Slight warpage at one end of stretch flange.

FINAL REPORT

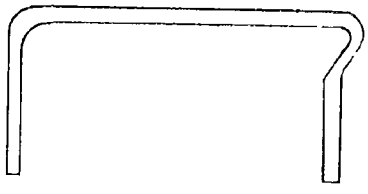
TABLE 3 (cont'd.)

Spec. No.	Operation	Remarks
A6	Impact rubber formed *1/2 inch hard lead overlay (1) Reduced heavy shrink flange wrinkles by hand forming with soft lead straps. (2) Restrike 2 times with no overlay. (3) Additional working of wrinkles with lead straps. (4) Restrike with no overlay.	1.60 stretch flange 1.06 shrink flange (1) Slight wrinkles not completely removed by hand working and restriking operations.

*The hard lead overlay consisted of lead alloyed with 6% antimony.

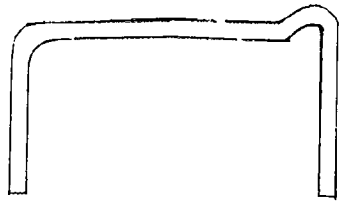


PART NO.	NOMINAL FLANGE WIDTH (IN.)		BEND ANGLE AFTER FORMING (DEGREES)									
			STRETCH					SHRINK				
	STRETCH	SHRINK	Ā	A	B	C	C̄	Ā	A	B	C	C̄
1	1.40	.86	⚠1	⚠1	⚠2	⚠1	3	2	3	2	3	⚠2
2	1.40	.86	3	3	4	3	1	2	4	3	3	0
3	1.40	.86	2	2	0	2	3	0	3	3	2	0
4	1.40	.86	1	1	4	3	2	2	4	4	4	2
A1	1.60	1.06	1	⚠1	⚠2	3	2	2	4	⚠1	1	1
A2	1.60	1.06	1	⚠1	2	⚠1	0	2	2	⚠2	3	3
A3	1.60	1.06	2	3	⚠1	⚠1	1	1	1	1	2	1
B1	1.40	.86	⚠1	⚠1	1	1	1	2	3	4	3	1
B2	1.40	.86	0	0	3	3	1	2	3	3	3	2
A4	1.60	1.06	0	1	1	3	3	1	2	⚠1	2	1
A5	1.60	1.06	1	⚠1	⚠2	⚠1	2	⚠2	2	2	2	⚠2
A6	1.60	1.06	3	2	1	2	3	2	2	⚠1	2	2

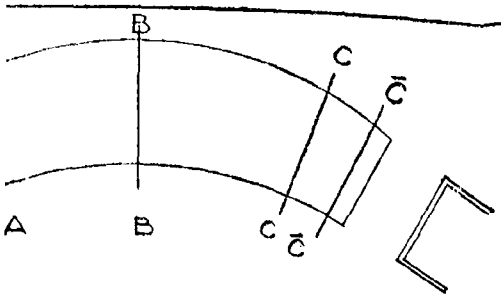


⚠1 NO VALUE - EXCESSIVE FLANGE DISTORTION

1

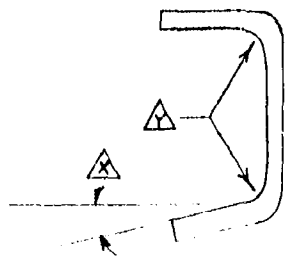


⚠2 NO VALUE - EXCESSI WEB WARPAGE



△1 - BEND RADII

△2 - BEND ANGLE



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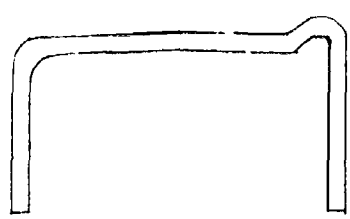
CRO

BEND ANGLE AFTER FORMING (DEGREES)							BEND RADII AFTER FORMING (IN.)										
'H		SHRINK					STRETCH					SHRINK					
C	C̄	Ā	A	B	C	C̄	Ā	A	B	C	C̄	Ā	A	B	C	C̄	Ā
HYDROFORMED																	
△1	3	2	3	2	3	△2	.109	.109	.109	.109	.109	.125	.109	.109	.109	.172	1.498
3	1	2	4	3	3	0	.094	.094	.109	.109	.109	.109	.109	.109	.109	.109	1.492
2	3	0	3	3	2	0	.109	.109	.109	.109	.109	.109	.109	.109	.109	.109	1.535
3	2	2	4	4	4	2	.094	.094	.109	.109	.109	.109	.109	.109	.109	.109	1.529
3	2	2	4	△1	1	1	.109	.109	.109	.094	.109	.094	.109	.109	.094	.109	1.779
△1	0	2	2	△2	3	3	.109	.109	.109	.109	.109	.109	.109	.125	.109	.109	1.768
△1	1	1	1	1	2	1	.094	.094	.094	.094	.094	.109	.094	.094	.094	.109	1.768
IMPACT RUBBER FORMED																	
1	1	2	3	4	3	1	.109	.109	.109	.109	.109	.109	.109	.109	.109	.109	1.544
3	1	2	3	3	3	2	.109	.109	.109	.109	.109	.109	.109	.109	.109	.109	1.533
3	3	1	2	△1	2	1	.109	.109	.094	.125	.109	.109	.109	.094	.109	.125	1.768
△1	2	△2	2	2	2	△2	.109	.141	.109	.109	.109	.141	.109	.094	.109	.141	1.797
2	3	2	2	△1	2	2	.094	.109	.109	.109	.109	.109	.109	.109	.109	.125	1.798



△2 NO VALUE-EXCESSIVE WEB WARPAGE

2

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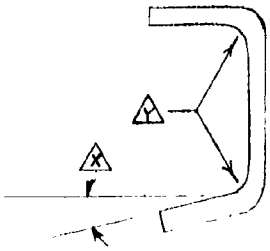
TABLE 4

- BEND RADII
BEND ANGLE



TYPICAL
CROSS-SECTION

BEND RADII AFTER FORMING (IN.)								FLANGE WIDTHS AFTER FORMING (IN.)									
TCH			SHRINK					STRETCH					SHRINK				
	C	C̄	Ā	A	B	C	C̄	Ā	A	B	C	C̄	Ā	A	B	C	C̄
ORMED																	
9	.109	.109	.125	.109	.109	.109	.172	1.498	1.378	1.298	1.420	1.564	.900	.935	1.024	.938	.888
9	.109	.109	.109	.109	.109	.109	.109	1.492	1.380	1.280	1.450	1.564	.905	.936	1.058	.946	.875
9	.109	.109	.109	.109	.109	.109	.109	1.535	1.398	1.275	1.473	1.564	.905	.952	1.040	.950	.898
9	.109	.109	.109	.109	.109	.109	.109	1.529	1.388	1.257	1.422	1.555	.918	.953	1.057	.968	.931
9	.094	.109	.094	.109	.109	.094	.109	1.779	1.628	1.405	1.650	1.779	1.148	1.183	1.333	1.195	1.156
9	.109	.109	.109	.109	.125	.109	.109	1.768	1.619	1.443	1.630	1.753	1.128	1.174	1.273	1.189	1.14-
4	.094	.094	.109	.094	.094	.094	.109	1.768	1.634	1.448	1.640	1.762	1.144	1.175	1.267	1.188	1.151
ER FORMED																	
9	.109	.109	.109	.109	.109	.109	.109	1.544	1.403	1.339	1.449	1.561	.893	.930	.984	.936	.881
9	.109	.109	.109	.109	.109	.109	.109	1.533	1.448	1.365	1.469	1.551	.887	.910	.923	.916	.904
4	.125	.109	.109	.109	.094	.109	.125	1.768	1.656	1.552	1.658	1.776	1.100	1.131	1.160	1.126	1.085
9	.109	.109	.141	.109	.094	.109	.141	1.797	1.656	1.484	1.672	1.807	1.088	1.134	1.261	1.149	1.084
9	.109	.109	.109	.109	.109	.109	.125	1.798	1.637	1.536	1.663	1.778	1.112	1.136	1.204	1.169	1.140

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TABLE 5

MINIMUM BEND RADIUS DATA FOR INCONEL 718

SPEC. NO.	GRAIN DIRECTION	MANDREL RADIUS (IN.)	SPRING BACK DEGREES	BEND CONDITION △1	MEASURED INSIDE BEND RADIUS △2
1	PARALLEL TO THE BEND AXIS	.031	—	CRACKED	
2			—		
3			—		
4		.047	8	HOP	3/64
5					
6					
7	PERPENDICULAR TO THE BEND AXIS	.016	—	CRACKED	
8			—		
9		.031	5	HOP	1/32
10			5		
11			4		
12		.047	3		
13					
14					

△1 HOP = HEAVY ORANGE PEEL

△2 VALUES RECORDED FOR SPECIMENS HAVING THE MINIMUM BEND RADIUS ONLY.

McDonnell Aircraft Corporation
ST. LOUIS 3, MISSOURI

FIGURE 1
TYPICAL STRESS STRAIN CURVE FOR AGED INCONEL 718 HEAT TREAT RESPONSE SPECIMENS

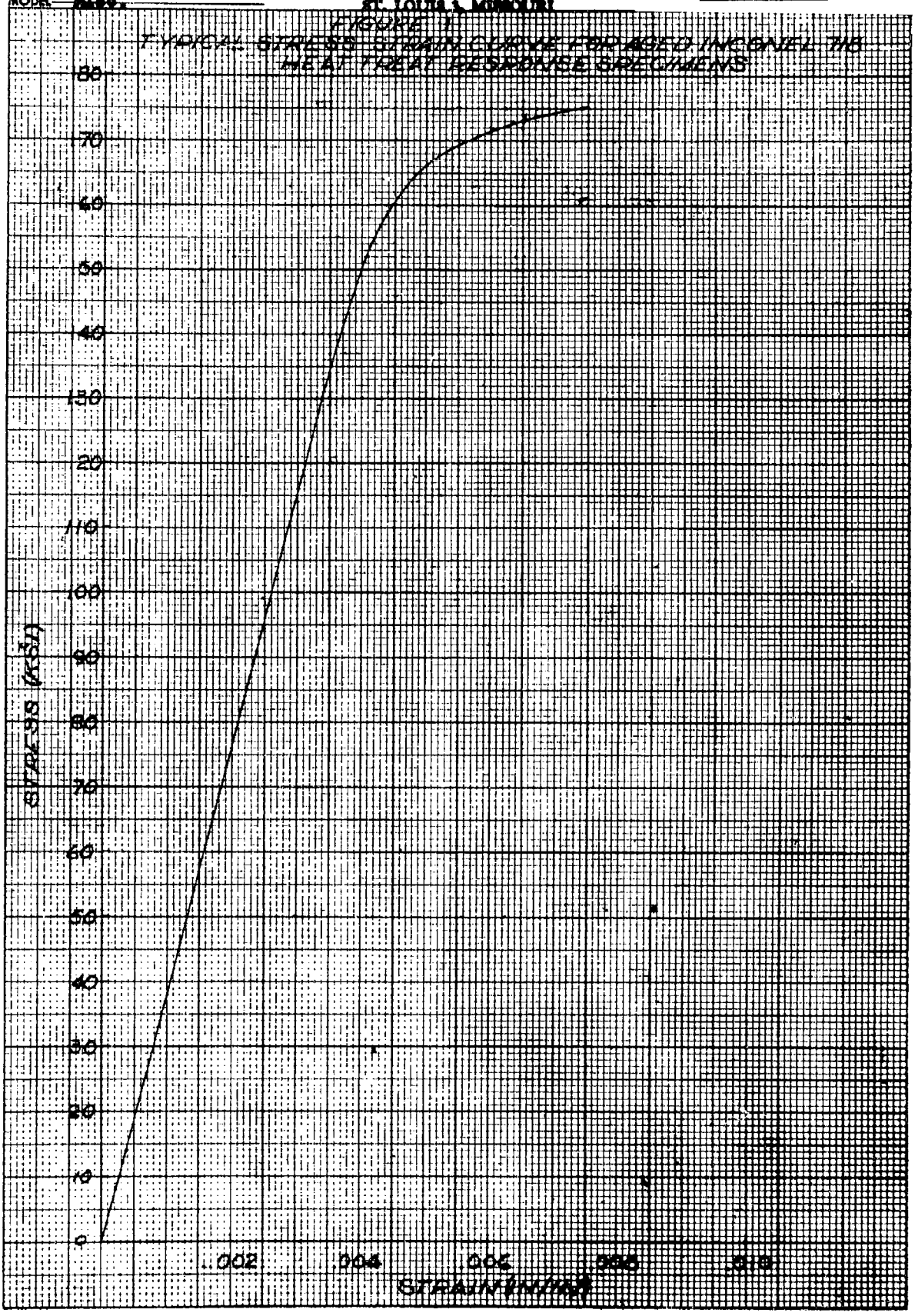

PHOTO D4E-248259

FIGURE 2 - LOCATION OF FAILURE IN CENTRAL HEAT TREAT TENSILE SPECIMENS

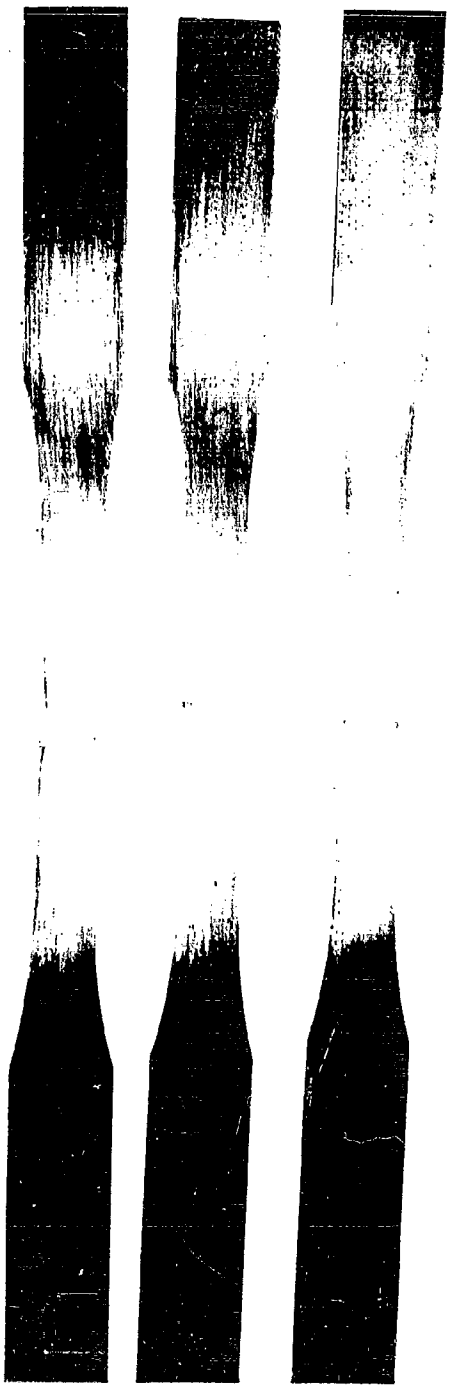

FIGURE 3
UNIFORM ELONGATION TEST SPECIMEN

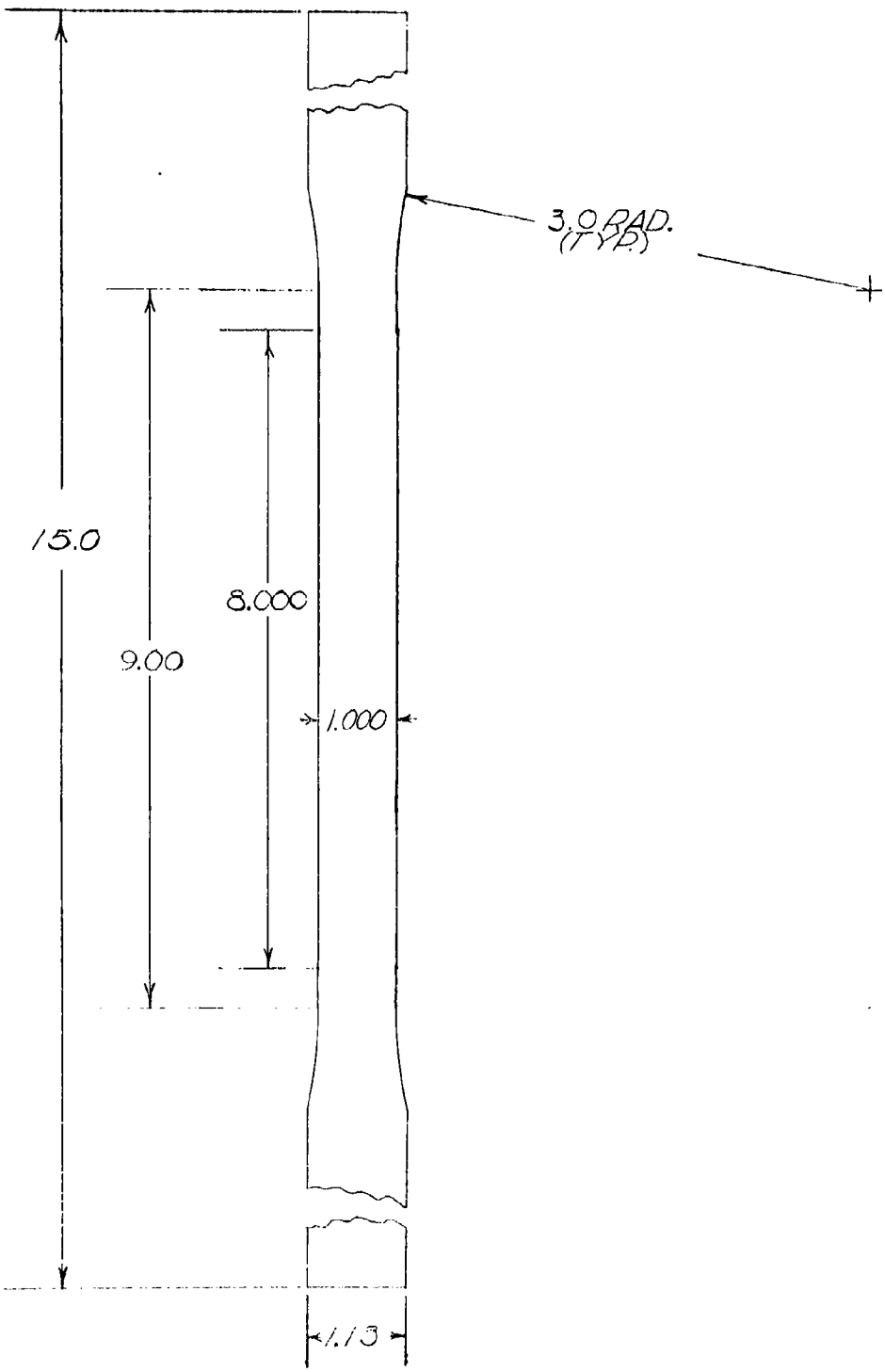

FIGURE 4

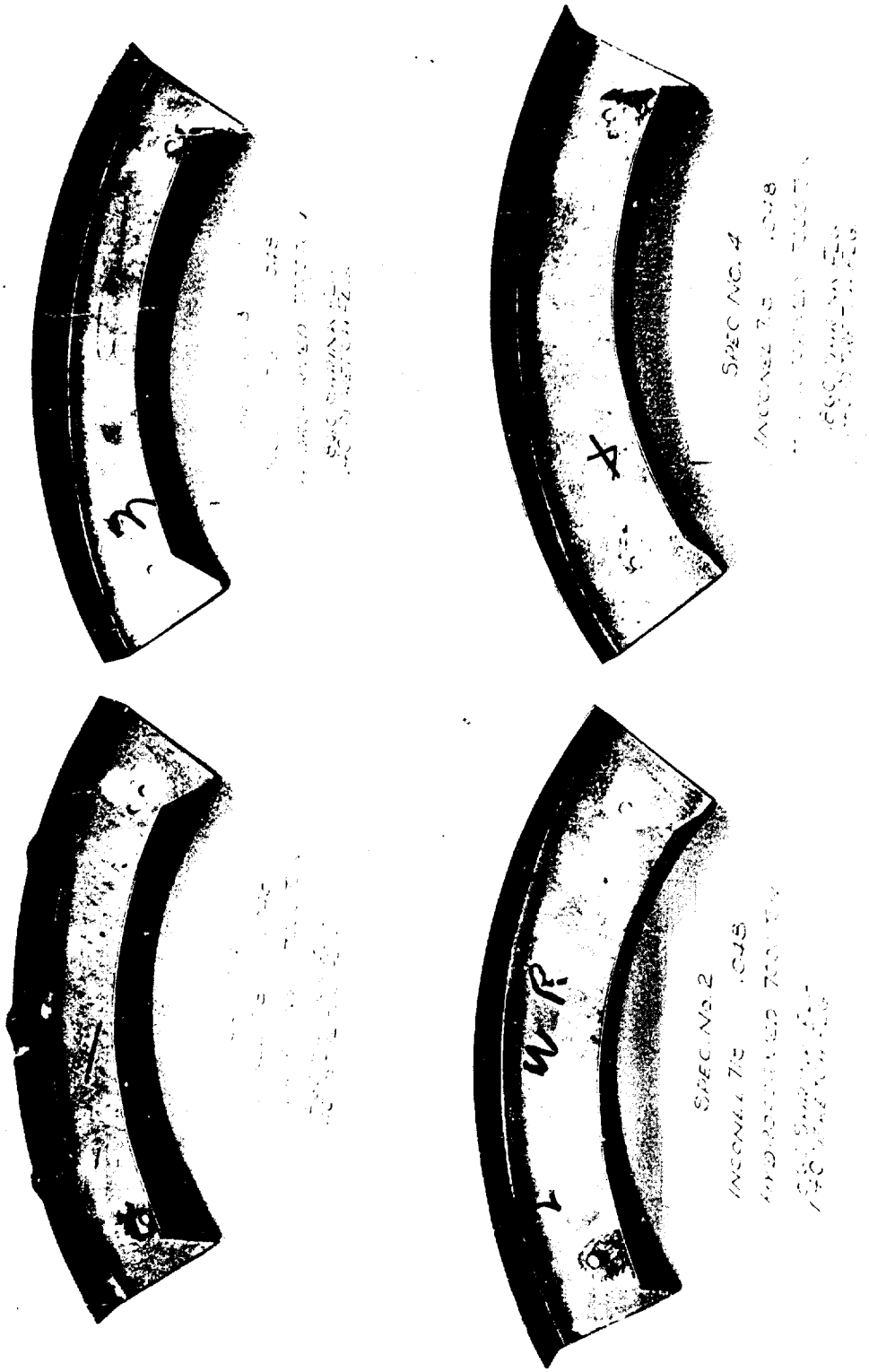

PHOTO D4E-254739

FIGURE 5

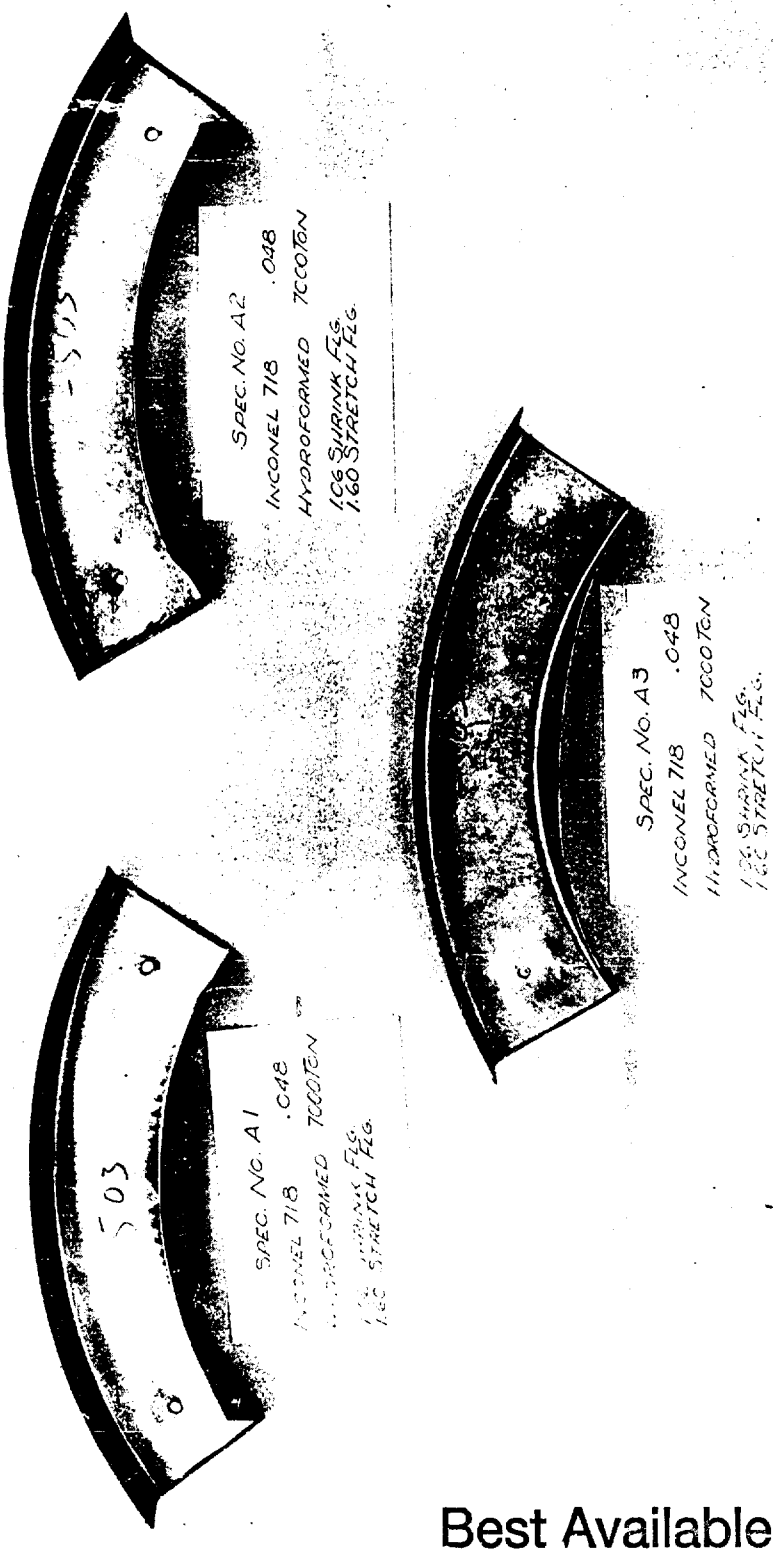

FIGURE 6

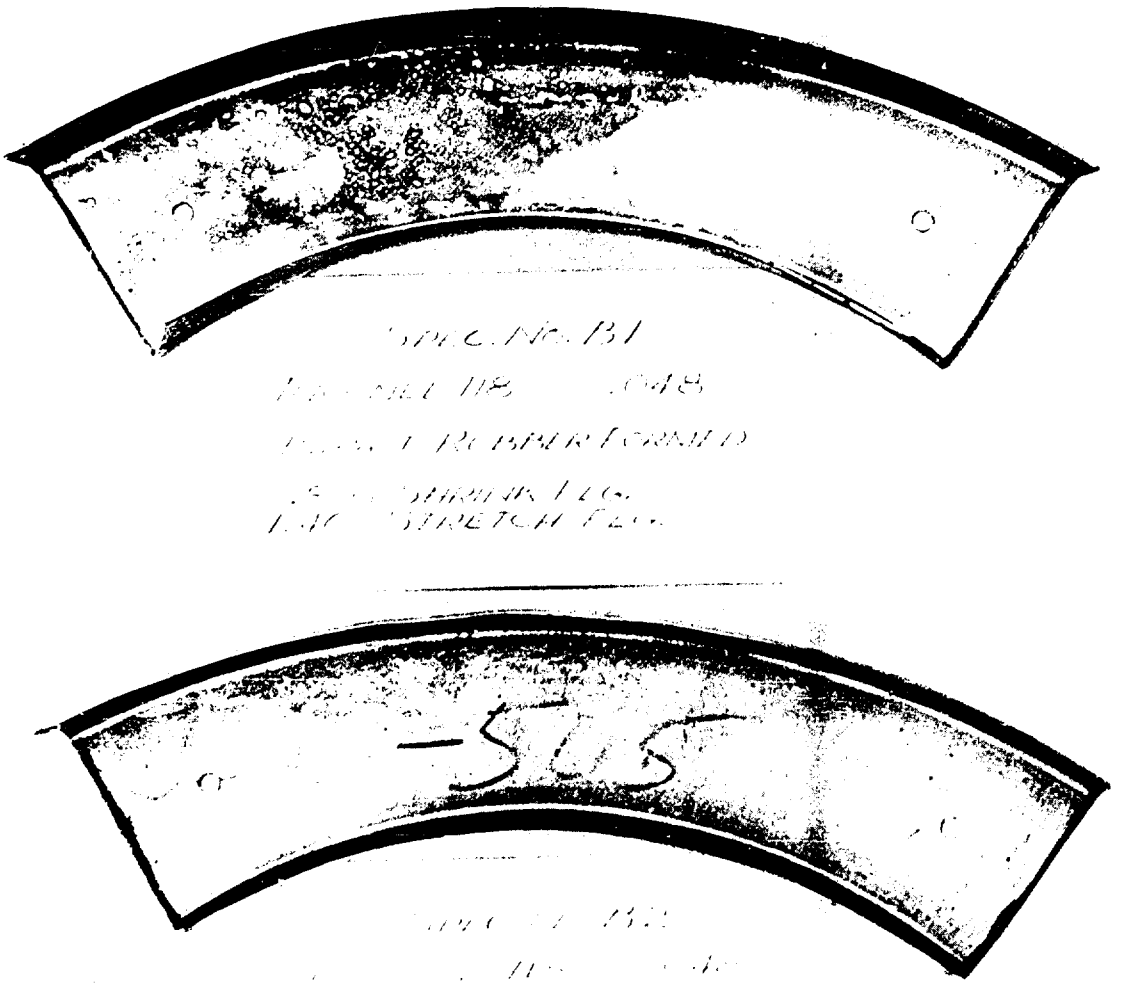

FIGURE 7

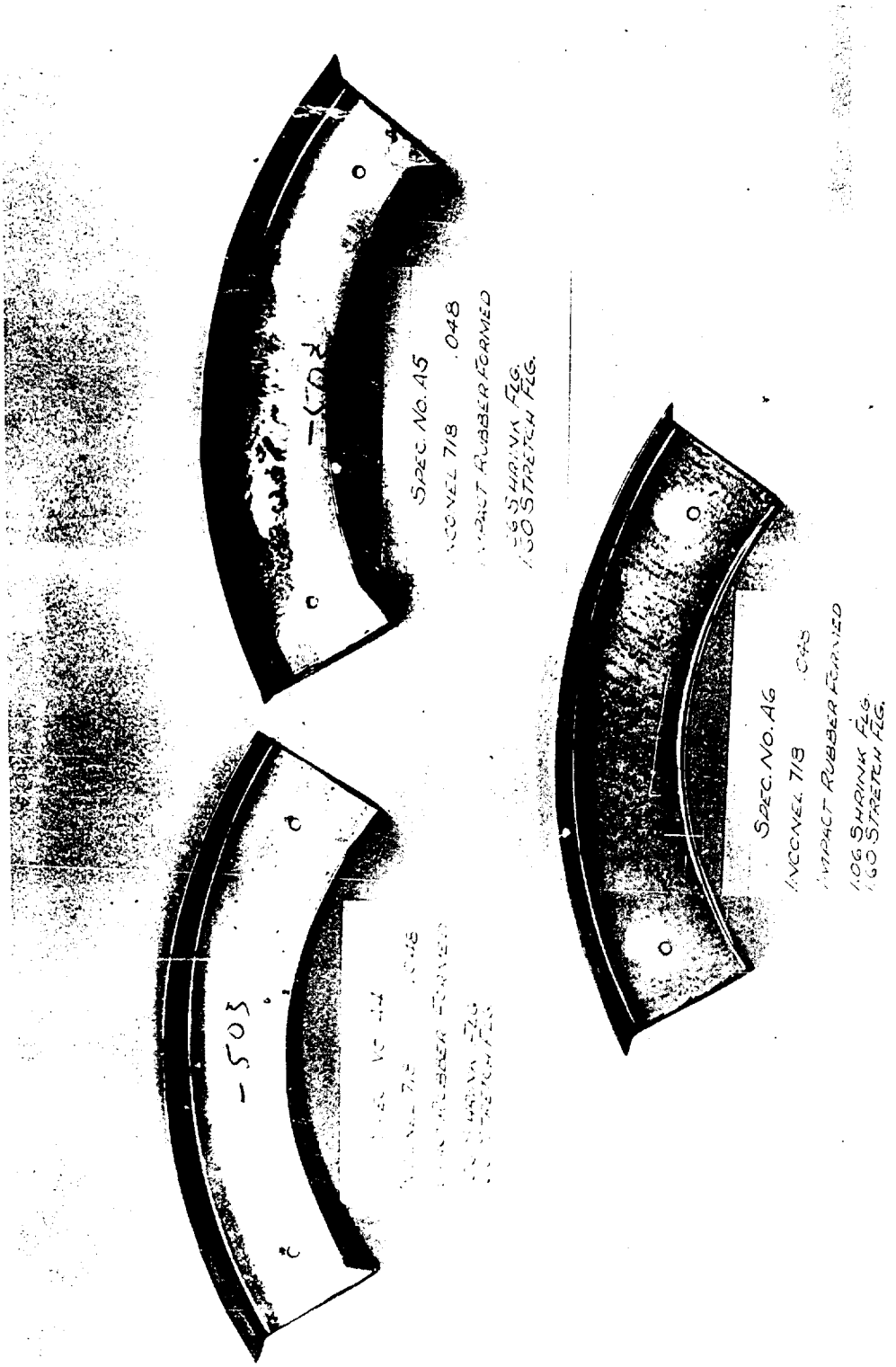

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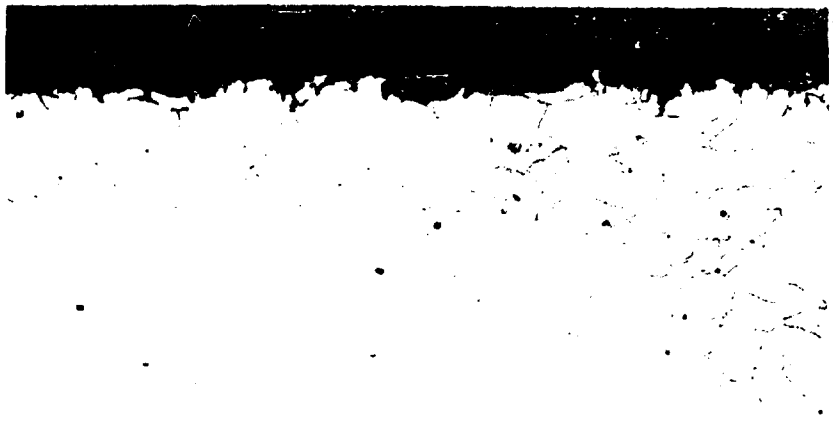
FIGURE 8 - INTERGRANULAR ATTACK IN BASE METAL OF 1/4 INCH INCONEL 718 PLATE MANUAL TIG WELDED WITH INCONEL 718 FILLER WIRE. WELDMENT WAS AGED AND PICKLED PER P.S. 12050 USING A HNO_3-HF SOLUTION



M-7389 MAG. 250X

M-7390 MAG. 250X

CORROSION IN HEAT AFFECTED ZONE OF WELDED PLATE

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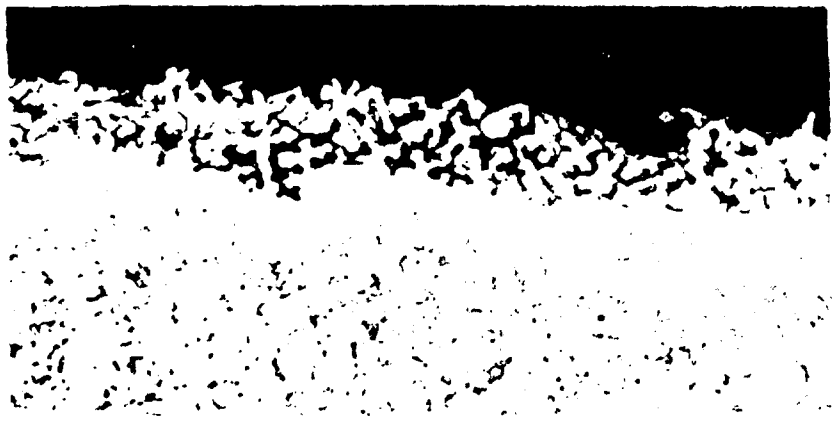
FIGURE 9 INTERDENDRITIC ATTACK OF WELD NUGGET IN TIG WELDED 1/4 INCH INCONEL 718 PLATE USING INCONEL 718 FILLER WIRE. WELD WAS AGED AND PICKLED PER P.S. 12050 AFTER WELDING USING A HNO_3-HF SOLUTION



M-7392 MAG. 250X

M-[illegible] MAG. [illegible]

FIGURE [illegible] INTERDENDRITIC ATTACK IN BASE METAL OF RESISTANCE [illegible] INCONEL 718 WELDMENT AGED AND PICKLED PER [illegible] SOLUTION

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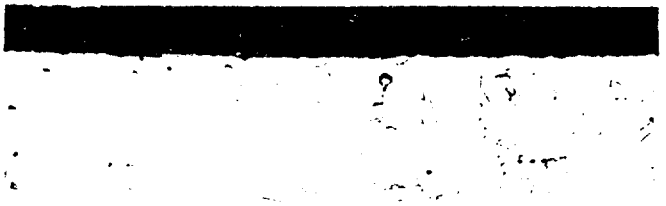
FIGURE 10 - .048 INCH THICK INCONEL 718



M-7762

AS-RECEIVED MILL ANNEALED

M-7804

AS AGED

M-7765

AGED AND PICKLED PER P.S. 12050

ALL PHOTOMICROGRAPHS - 250X
ETCH: ELECTROLYTIC - HCL + H_2O_2

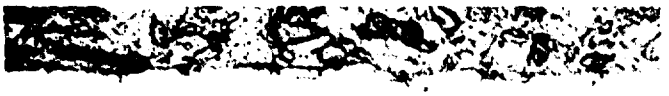
FIGURE 11 - AGED .048 INCH INCONEL 718 PICKLED FOR [illegible]
USING PRODUCTION FACILITIES

M-[illegible]

PICKLED FOR [illegible] MINUTES

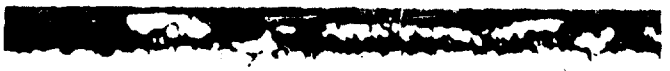
M-7805

PICKLED FOR 30 MINUTES



M-7807

PICKLED FOR [illegible] MINUTES

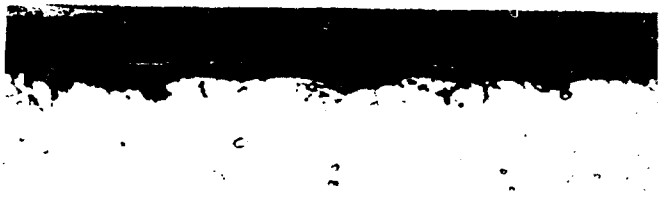


M-[illegible]

[illegible]

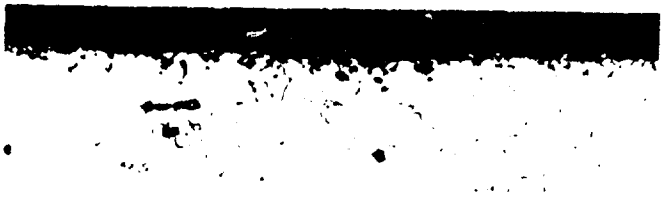
FINAL REPORT

FIGURE 2 AGED .040 INCH INCONEL 718 PICKLED PER U.S. 120[illegible] USING PRODUCTION FACILITIES



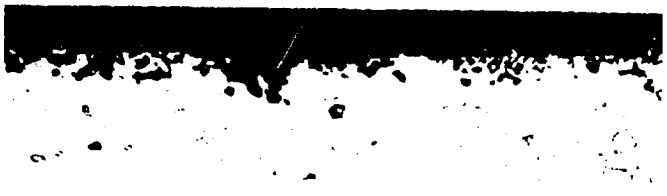
M-7761

PICKLED FOR 75 MINUTES



M-7760

PICKLED FOR 90 MINUTES



M-7764

PICKLED FOR 105 MINUTES

M-7763

PICKLED FOR [illegible] MINUTES

DATE
BY
D49-25907

FIGURE 15 - AGED .048 INCH INCONEL 718 PICKLED PER [illegible] 12050 USING LABORATORY FACILITIES

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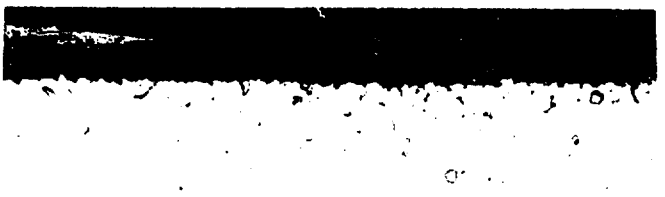
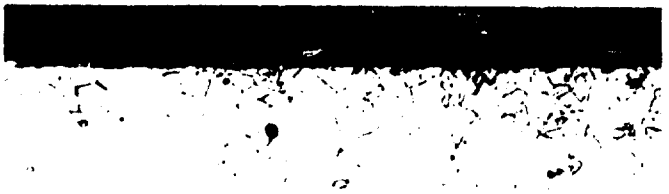


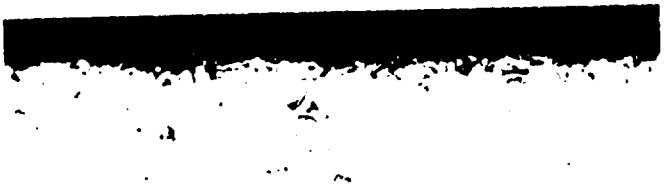
M-7858

PICKLED FOR 15 MINUTES



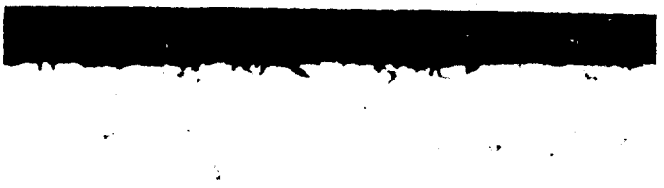
M-7856

PICKLED FOR 30 MINUTES



M-7855

PICKLED FOR 45 MINUTES



M-7859

PICKLED FOR 60 MINUTES

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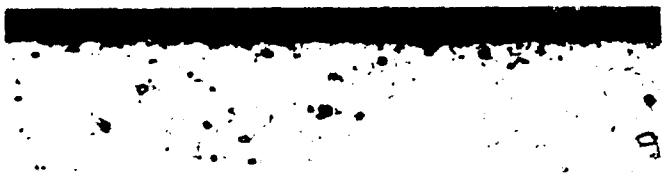
FIGURE 14 - AGED .048 INCH INCONEL 718 PICKLED PER P.S. 12050 USING LABORATORY FACILITIES



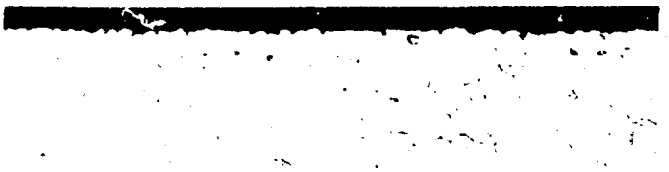
M-7873

PICKLED FOR 75 MINUTES

M-7857

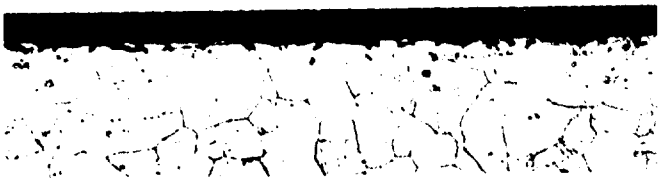
PICKLED FOR 90 MINUTES

FIGURE 15 . . .040 INCH INCONEL 718 PICKLED PER . . .
AFTER BEING RE-ANNEALED AND AIR QUENCHED



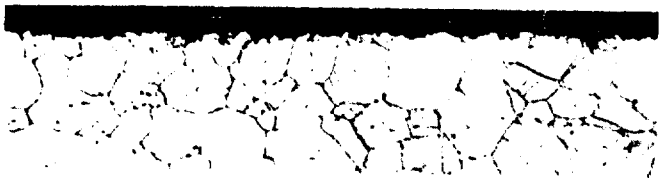
M-8004

PICKLED FOR 15 MINUTES



M-8003

PICKLED FOR 30 MINUTES



M-8002

PICKLED FOR 45 MINUTES

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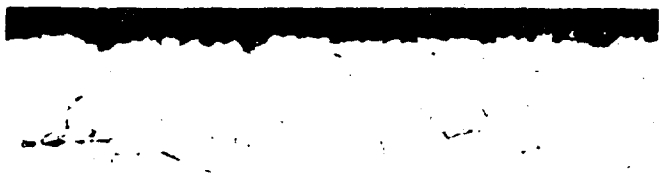
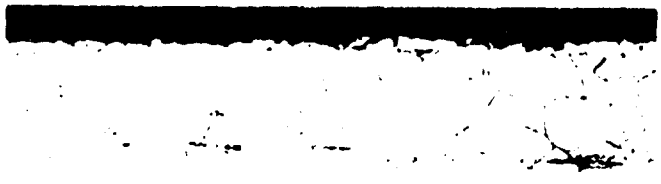
FIGURE 16 - .048 INCH INCONEL 718 PICKLED PER P.S. 12050
AFTER BEING RE-ANNEALED USING A WATER QUENCH



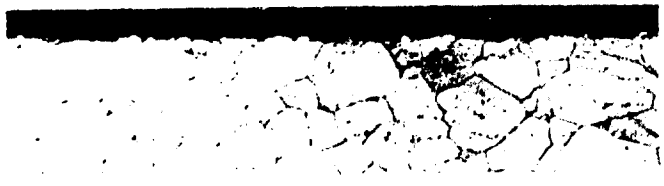
M-8094

PICKLED FOR 15 MINUTES



M-8095

PICKLED FOR 30 MINUTES



M-8059

PICKLED FOR 45 MINUTES

D&E- 255011

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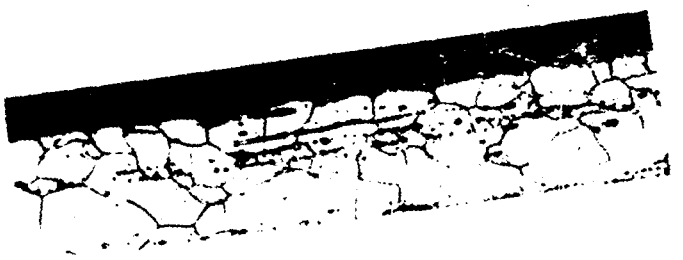
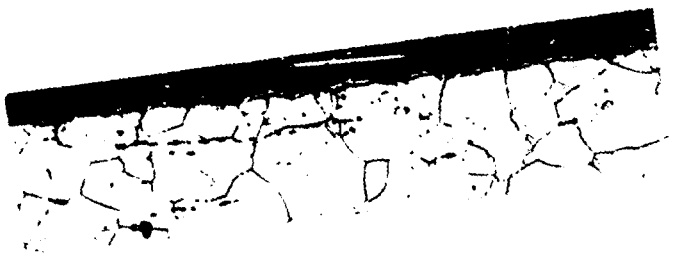
FIGURE 17 - AGED .048 INCH INCONEL 718 PICKLED USING THE PROCEDURE PUBLISHED BY THE INTERNATIONAL NICKEL COMPANY



M-8342

PICKLED FOR 15 MINUTES



M-8340

PICKLED FOR 30 MINUTES

M-8341

PICKLED FOR 60 MINUTES

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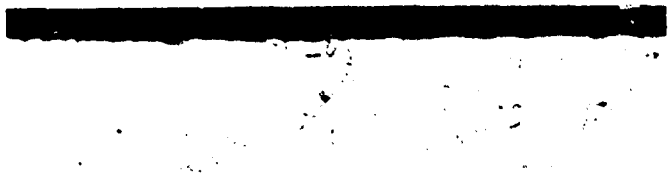
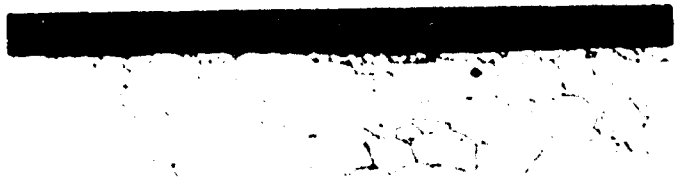
FIGURE 18 - AGED .048 INCH INCONEL 718 PICKLED USING A NITRIC ACID-NITRADD PICKLING SOLUTION



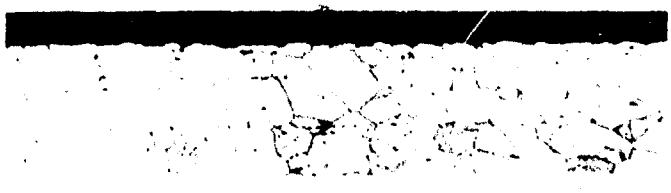
M-8527

PICKLED FOR 15 MINUTES



M-8532

PICKLED FOR [illegible] MINUTES



M-8547

PICKLED FOR [illegible] MINUTES

FIGURE 19 - MINIMUM BEND RADIUS SETUP

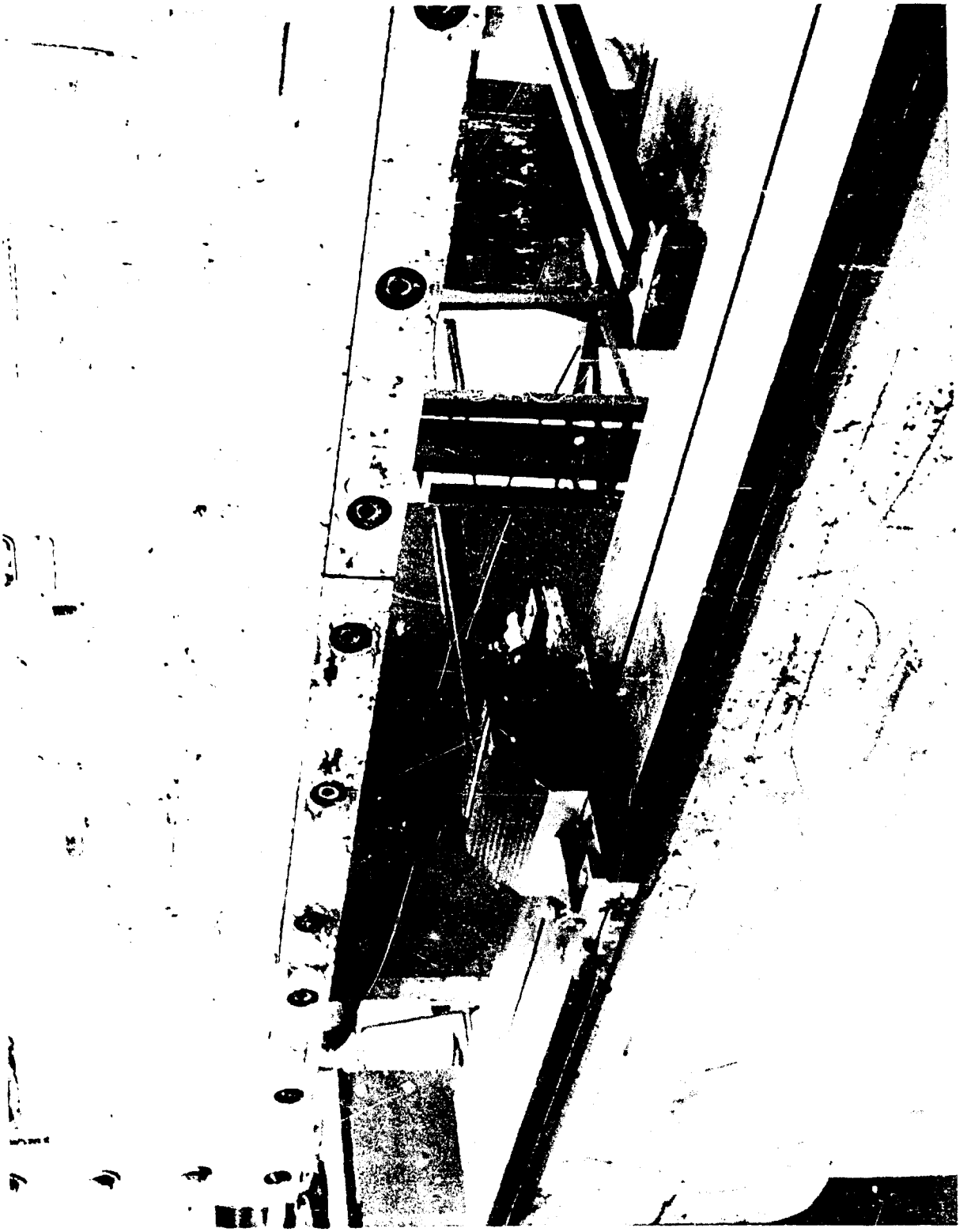
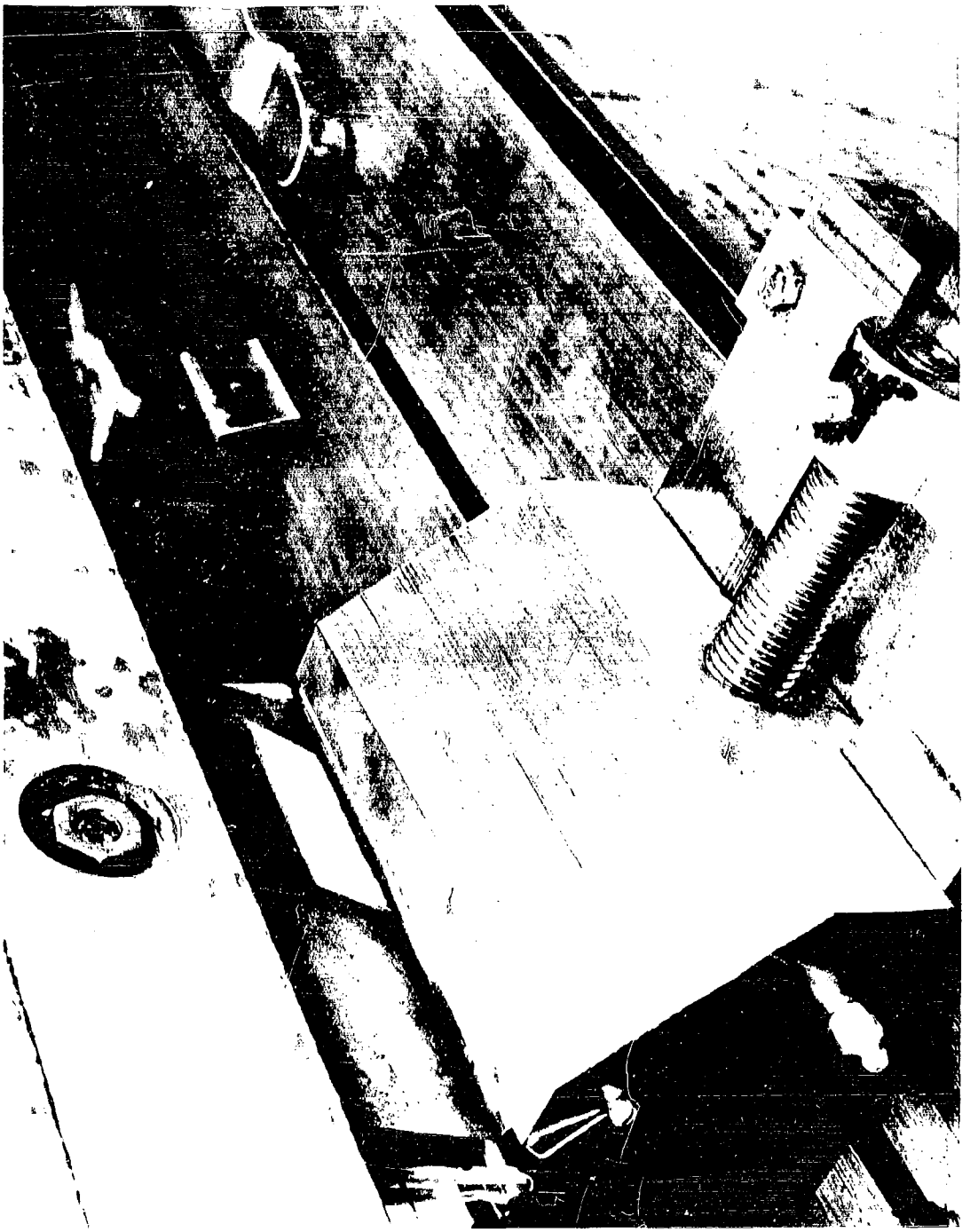


FIGURE 20 - SPECIMENS BEING BENT IN BEND RADIUS TEST TOOL



TEST REQUEST

TITLE Evaluation of Inconel 718, Age Hardenable Nickel-Chromium Alloy

LABORATORY OR DEPT. RESPONSIBLE FOR TEST	MODEL
	Misc.
TEST PARTS ON IBM ☐, ON TPL NO. _____ PRODUCTION PARTS FOR TEST NOT REQUIRED ☒	APL/EPI None

WORK REQUESTED

OK for IDEP

OBJECTIVE (GIVE PURPOSE OF TEST, WORK AND DATA REQUIRED INCLUDING SERVICE HISTORY AND BACKGROUND INFORMATION)

1.0 OBJECT

To continue the determination of the fabrication characteristics of the nickel-chromium alloy, Inconel 718.

F6875-0725

2.0 JUSTIFICATION

Results of the testing which has been completed in Phase I justify the continuation of this program.

3.0 WORK TO BE PERFORMED

Work to be performed under this addendum to TR. 513-241 will be as stated in page 3 of the basic TR. as Phase II and III:

Phase II

3.1.1.3 Weld Patch Test
3.1.2.1 Tensile Properties, Manual TIG Fusion Welded Plate
3.2.1 Lap Shear, Resistance Spot Weld
3.2.2 Tensile Pull-Out, Resistance Spot Weld
3.3.1 Lap Shear, TIG Spot Weld
3.3.2 Tensile Pull-Out, TIG Spot Weld

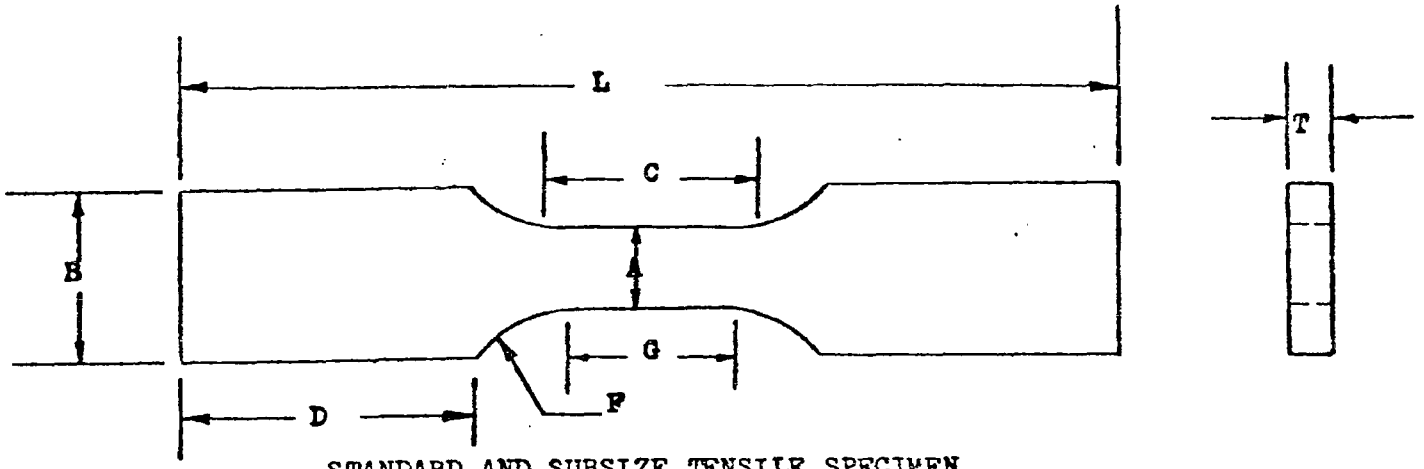
Phase III

4.1 Delete (Work completed under Phase I)
4.2 Uniform Elongation
4.3 Dimpling
4.4 Rubber Forming

REFERENCES OR ENCLOSURES

REF.: TR. No. 513-241

Rev B ADD ACTUALS 10-30-62 CM



STANDARD AND SUBSIZE TENSILE SPECIMEN

DIMENSIONS	F1	F2 was	F2 now	F3	
A - WIDTH AT CENTER	1.50 $^{+.125}_{-.260}$	.50 $\pm$.01	.500 $\pm$.010	.500	
B - WIDTH AT GRIPS, APPROX.	2.00	.75	.75	.75	
C - LENGTH OF REDUCED SECTION	9.00 (Min.)	2.25(Min)	2.50(Min.)	1.25	
D - GRIP LENGTH	3.0(Approx.)	2.375(Min.)	2.375(Min.)		2
F - FILLET RADIUS, MIN.	1.00	.50	3.00	.50	
G - GAGE LENGTH	8.00 $\pm$.01	2.000 $\pm$.005	2.000 $\pm$.005	1.00	
L - TOTAL LENGTH, MIN.	15.0	8.0	10.0		2
T - THICKNESS	.375 to 2.00	.500Max.	.500Max.	25 or less	

NOTES:

1. Reduced section must be parallel within .002
2. To be determined by length of available stock.
3. The reduced section shall be parallel to within .002.
4. Under no circumstances shall the diameter of the ends of the reduced section be less than the diameter of the center.